NATIONAL ENERGY TECHNOLOGY LABORATORY

Advanced Coal Power Market Penetration under Carbon Taxation

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Overview

- **NETL exercised the NEMS AEO2009 ARRA version to model the benefits of advanced coal R&D**

- **Highlights:**
  - Slower GDP growth combined with higher capital costs lead to fewer coal power deployments than previous AEOs, approximately 30 GW by 2030
  - NETL R&D scenario refurbishes and retrofits most of the coal fleet under moderate CO_2 tax levels (starting at $18/tonne in 2012 and rising to $43/tonne by 2030)
  - NETL R&D programs reduce GHG emissions without increasing average electric bills

Results Summary: Coal Power with CCS in NEMS through 2030, GW

Total new and retrofit (retrofit)

		CO_2 Tax Scenarios		
		Low ($10 in 2012 - $24 in 2030)	Mid ($18 in 2012 - $43 in 2030)	High ($25 in 2012 - $60 in 2030)
PC Retro Not Allowed	No R&D	2	3	6
	NETL R&D	21	26	31
PC Retro Allowed	No R&D	2 (0)	2 (0)	46 (42)
	NETL R&D	26 (22)	211 (188)	205 (188)

Retrofit capacity based on power plant capacity after retrofit (includes parasitic load)

Presentation Outline

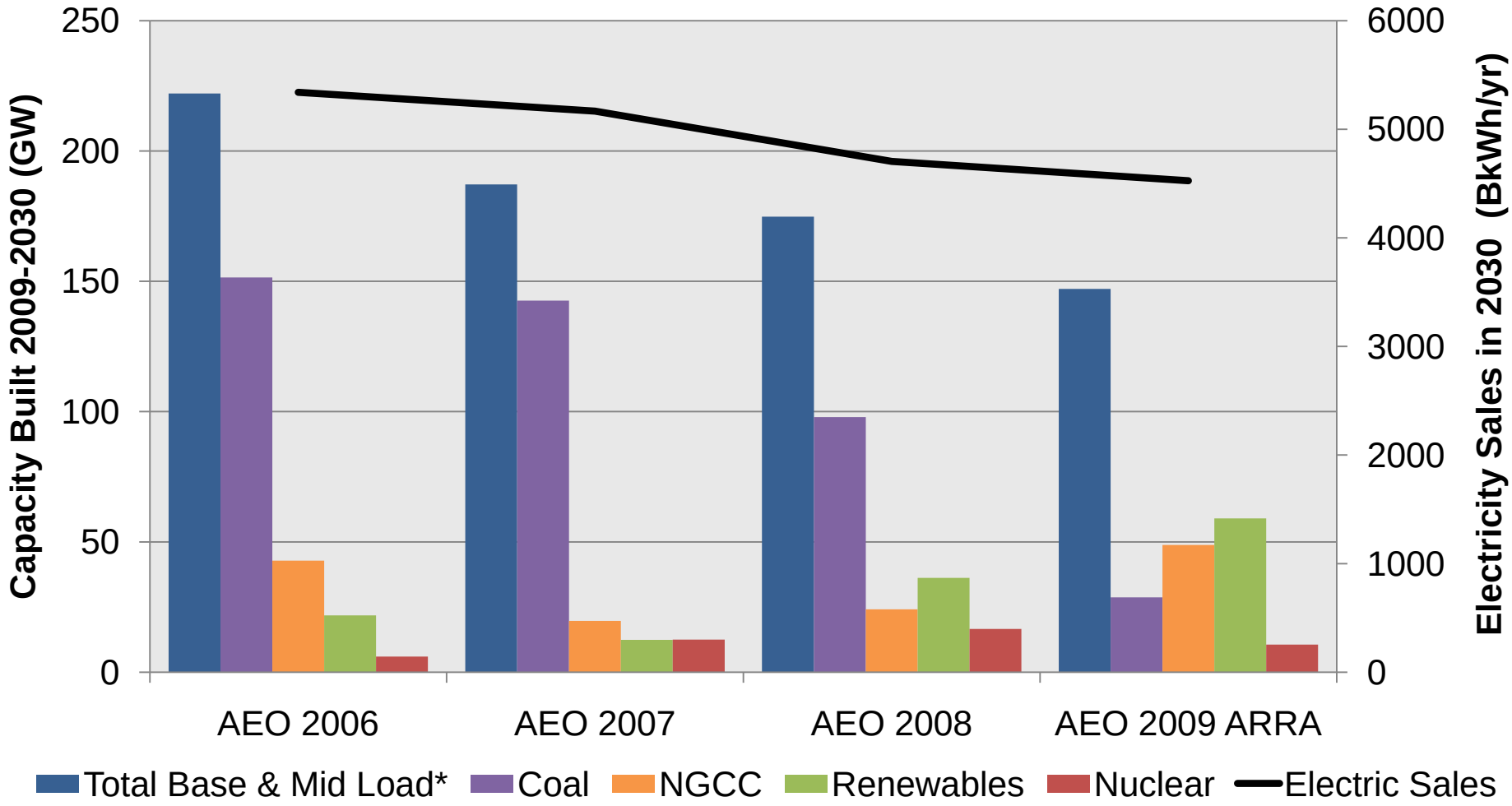
1. Power Sector Results from NEMS Annual Energy Outlook 2009 Reference Case Scenario

2. NEMS Results with Inputs Changed to Represent FE R&D for advanced coal power (new builds only)

3. NEMS Results with (1) Inputs Changed to Represent FE R&D for Advanced Coal Power and (2) NEMS Code Modified to Allow PC retrofits for CO2 capture

1. Power Sector Results from AEO 2009 Reference Case Scenario (ARRA version, no FE R&D impacts)

2030 Electric Growth Projections Impact New Baseload Builds



**Excludes new distributed generation and CT builds.*

Source: EIA NEMS AEO2006 – 2009 Results

Fewer Power Plant Deployments Caused by

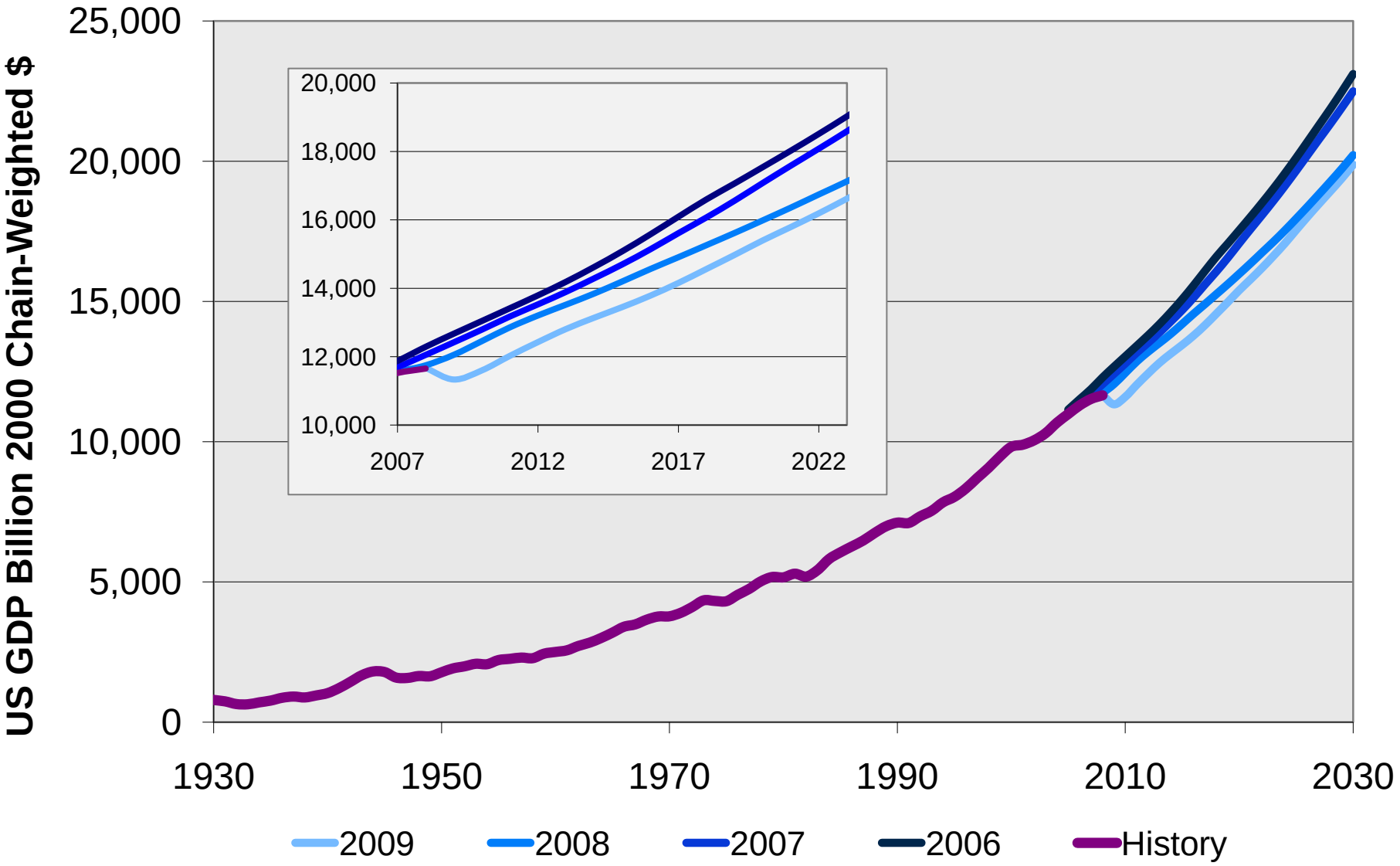
- **Lower Electric Demand**
  - AEO2006: 5300 billion kWh in 2030, AEO2009: 4500 billion kWh
  - Recession causes slower near and mid term GDP growth
  - Electric Intensity profile similar to AEO2008, starting at .33 in 2008 and decreasing to .24 kwh/gdp by 2030

    Electric intensity = kWh / GDP

- **Higher LCOE**
  - Increases in fuel costs
    - 2030 coal prices, 10% higher than AEO2008
    - 2030 natural gas prices, 17% higher than AEO2008
  - Power Plant capital costs higher than AEO2008 for most technologies
    - PC, 75%
    - NGCC, 63%
    - Nuke, 46%

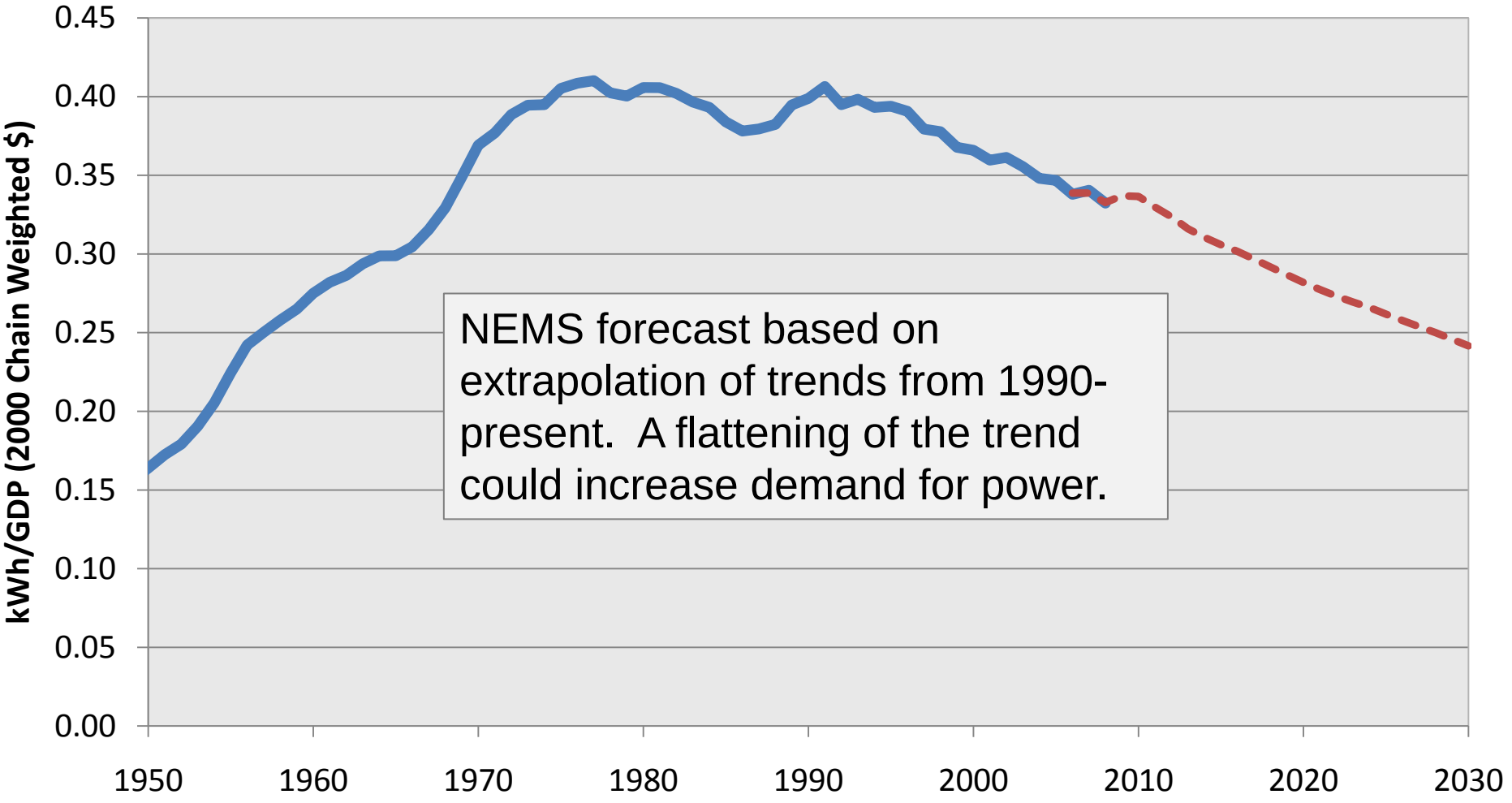
- **Higher electric prices reinforces drop in demand**

NEMS US GDP Projections



Source: Historical Data from BEA, NEMS Projections from EIA AEO Reference Case Results

Electric Intensity - Historical and NEMS Projected



Source: Historical Data from EIA AER and BEA, NEMS Projections from EIA AEO2009 ARRA Case Results

Decrease in Coal Builds Caused By

- **3% Risk Premium** added to financing rate for carbon intensive projects, impacts coal without CCS only

- **Renewable Portfolio Standards**
  - Reflects current state requirements which vary from 8% by 2020 in PA to 40% by 2017 in ME
  - NEMS tries to meet RPS standards first then builds plants based on lowest LCOE

Higher LCOEs cause decrease in Coal Builds

AEO2008 – 2015 LCOEs, 85% CF

	PC	IGCC	NGCC
Capital	30.5	28.7	13.4
Fixed O&M	3.6	5.1	1.5
Variable O&M	21.6	17.9	43.9
Transmission	3.6	3.5	3.6
Total	**59.3**	**55.1**	**62.4**

AEO2009 – 2015 LCOEs, 85% CF

	PC	IGCC	NGCC
Capital	52.9	58.5	21.5
Fixed O&M	3.7	5.2	1.6
Variable O&M	22.7	19.2	51.8
Transmission	3.5	3.5	3.7
Total	**82.8**	**86.4**	**78.6**

- **LCOEs increases across the board from AEO2008 to AEO2009.**
- **Coal is no longer the cheapest baseload option in most regions, but LCOE is within market sharing.**
- **Recession causes demand for mid load power until 2025, and at lower capacity factors NGCC is the cheapest option.**

Nuclear unavailable in year 2015, and NEMS does not report an LCOE

2. NEMS Results with Inputs Changed to Represent FE R&D for advanced coal power (new builds only)

How Market Penetration is Modeled

1. **EIA NEMS AEO2009 ARRA version used as basis**
   - NEMS - general equilibrium model that forecasts the US energy sector through 2030

2. **Modifications are made to NEMS inputs to represent the effect of FE R&D**

3. **Compare results of with and without NETL R&D scenarios to estimate impacts**

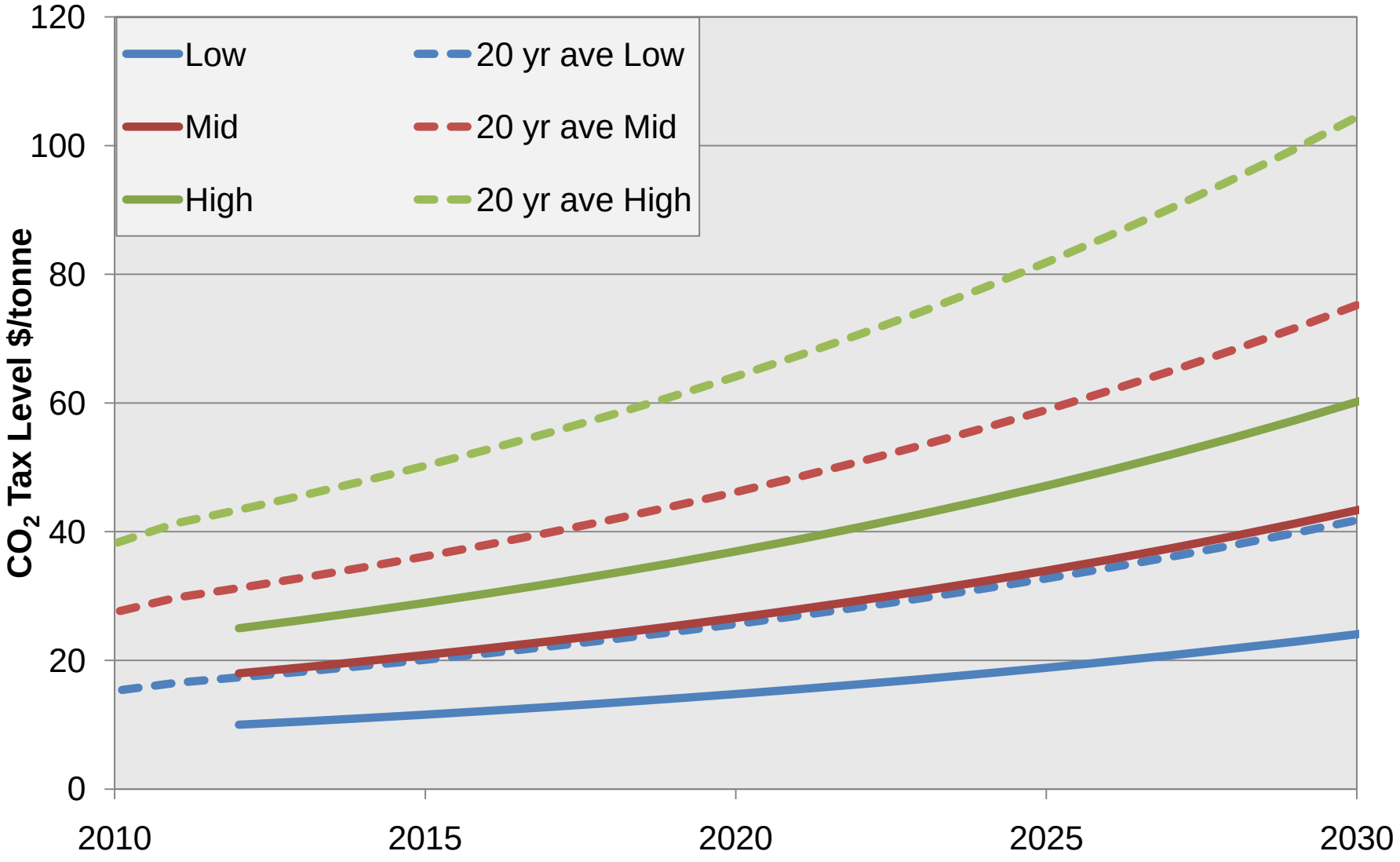
4. **Repeat using different assumptions for CO_2 taxes and economic growth forecasts**

Assumptions for CO_2 Tax Scenarios

- **3% risk premium removed, assumes investments in coal no longer risky once a carbon tax is in place**
- **10, 18, 25 $/metric ton starts in 2012**
- **Rises at 5% per year to mimic cap and trade bills**
  - EIA Waxman Markey Cap and Trade Runs allow CO_2 allowance prices to rise no more than 5-7.4% based on the discount rate of the electric power sector*.
  - NEMS uses carbon tax projections out to 2050 when deciding what plants to build in 2030 since LCOE is levelized over 20 years.
  - Since CO_2 tax escalation compounds out to 2050, the low range, 5% was used.

* Energy Information Administration / Energy Market and Economic Impacts of H.R. 2454, the ACESA of 2009, pg 56

CO_2 Tax Scenarios



Model Inputs, No NETL R&D

- **IGCC with and without CCS allowed to build**
- **Online year: IGCC 2012, IGCC w/ CCS 2016**
- **Heat rate adjustment**
  - Starting heat rates were lower than NETL pathway study
  - Adjusted starting heat rate to match pathway study
  - Allowed ending heat rate to decline by same percent as original
- **Capital costs remained unchanged to keep all plant types within NEMS on relative cost basis**

Model Inputs, With NETL R&D, IGCC w/ CCS

- **Online year: 2014**
- **Heat rates through 2030 are consistent with NETL pathway study.**
- **Starting year capital costs consistent with no R&D case to keep coal power , NGCC and nuclear on consistent basis**
- **NEMS learning function**
  - Allows for reduction in capital costs as individual power plant technology components are deployed
  - In the past, year by year capital costs were hardwired disabling NEMS built in learning function . Specifying only a starting capital cost allows us to utilize NEMS learning function under both cases.
  - NETL R&D areas, gasifiers, turbines, CCS, allowed to learn faster than no R&D case
  - Using this method, not only IGCC plants realize benefits of NETL R&D, ex, advanced turbine learning impacts NGCC and CT
  - Overall result mimics NETL pathway studies when technologies deploy

Model Inputs, With NETL R&D, IGFC w/ CCS

- **Under tax scenarios, non CCS coal technologies are not deployed.**
- **To allow IGFC to be modeled, we replaced IGCC without capture with IGFC with CCS.**
- **Online year: IGFC w/CCS 2023**
- **Capital costs and heat rates consistent with pathway study.**
- **IGFC costs had to be hardwired because of NEMS limitation.**

NEMS Input Summary

		No NETL R&D		With NETL R&D	
Surcharge: carbon-intensive technologies		Removed		Removed	
IGCC	Capital Cost (1987$/kW)	1358		Not Modeled in B case to allow for IGFC with CCS	
	Fixed O&M (1987$/kW)	23.624			
	Variable O&M (1987$/kWh)	1.785			
	Online Year	2012			
	Starting Heatrate (Online)	9649			
	Ending Heatrate (2030)	8202			
	Maximum capacity factor	0.80			
IGCC w/CCS	Capital Cost (1987$/kW)	1938		1938	
	Fixed O&M (1987$/kW)	28.176		28.176	
	Variable O&M (1987$/kWh)	2.713		2.713	
	Online Year	2016		2014	
	Starting Heatrate (Online)	10839		10839	
	Ending Heatrate (2030)	8792		8346	
	Maximum capacity factor	0.80		0.85	
IGFC w/CCS	Capital Cost (1987$/kW)	Not Modeled in A case because IGFC assumed not to be developed without NETL R&D		1238	
	Fixed O&M (1987$/kW)			28.176	
	Variable O&M (1987$/kWh)			2.713	
	Online Year			2023	
	Starting Heatrate (Online)			6064	
	Ending Heatrate (2030)			6064	
	Maximum capacity factor			0.90	
Learning Factors		**Vintage**	**Minimum Learning**	**Vintage**	**Minimum Learning**
	Advanced Turbines	Evolutionary	0.10	Revolutionary	0.20
	Steam Combined Cycle	Conventional	0.05	Conventional	0.05
	Gasifier	Evolutionary	0.10	Revolutionary	0.20
	Sequestration	Evolutionary	0.10	Revolutionary	0.20
	Balance of Plant	Conventional	0.05	Conventional	0.05

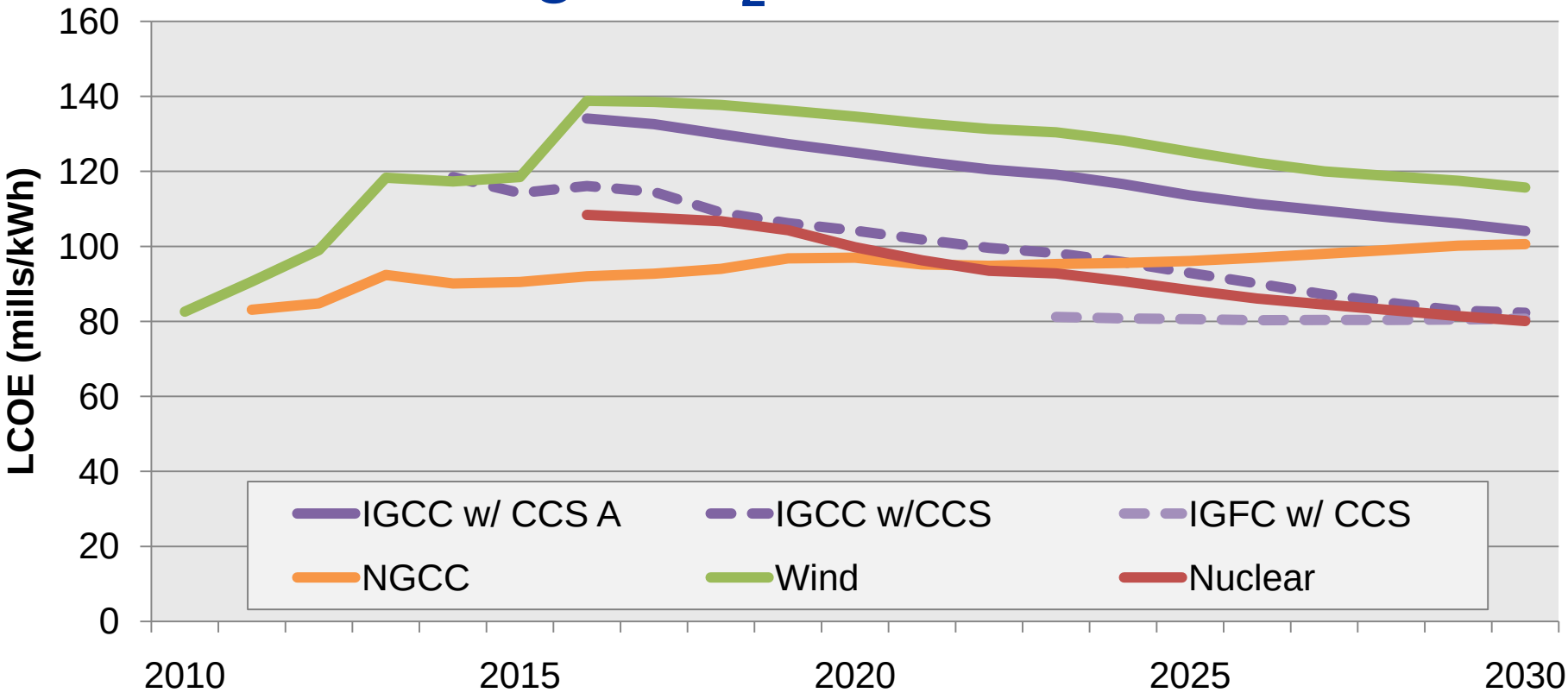
Adjustments to model the impact of R&D programs are done within the NEMS learning curves.

Cost and performance of each technology is based on assumed pathway of efficiency and capacity.

Technology component's learning rate is reflected by reductions in capital costs.

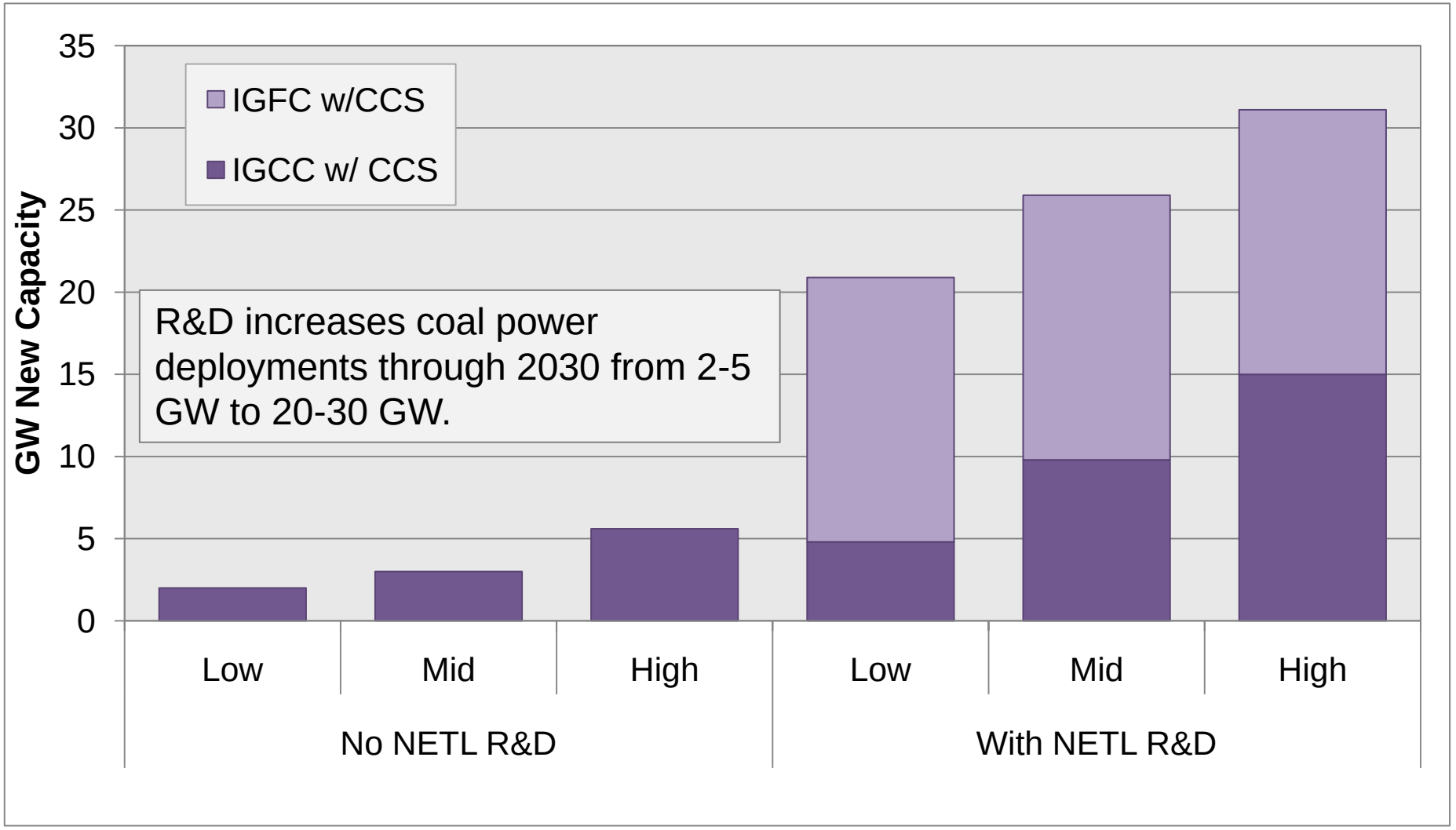
IGFC w/CCS is defined as a new technology option that is not modeled without NETL R&D.

NETL R&D Impacts on Baseload LCOE in High CO_2 Tax Case



- **IGCC does not beat out nuclear**
- **IGCC is lower than NGCC starting in 2024**
- **IGFC enters at 2023 lower than both nuclear and NGCC**

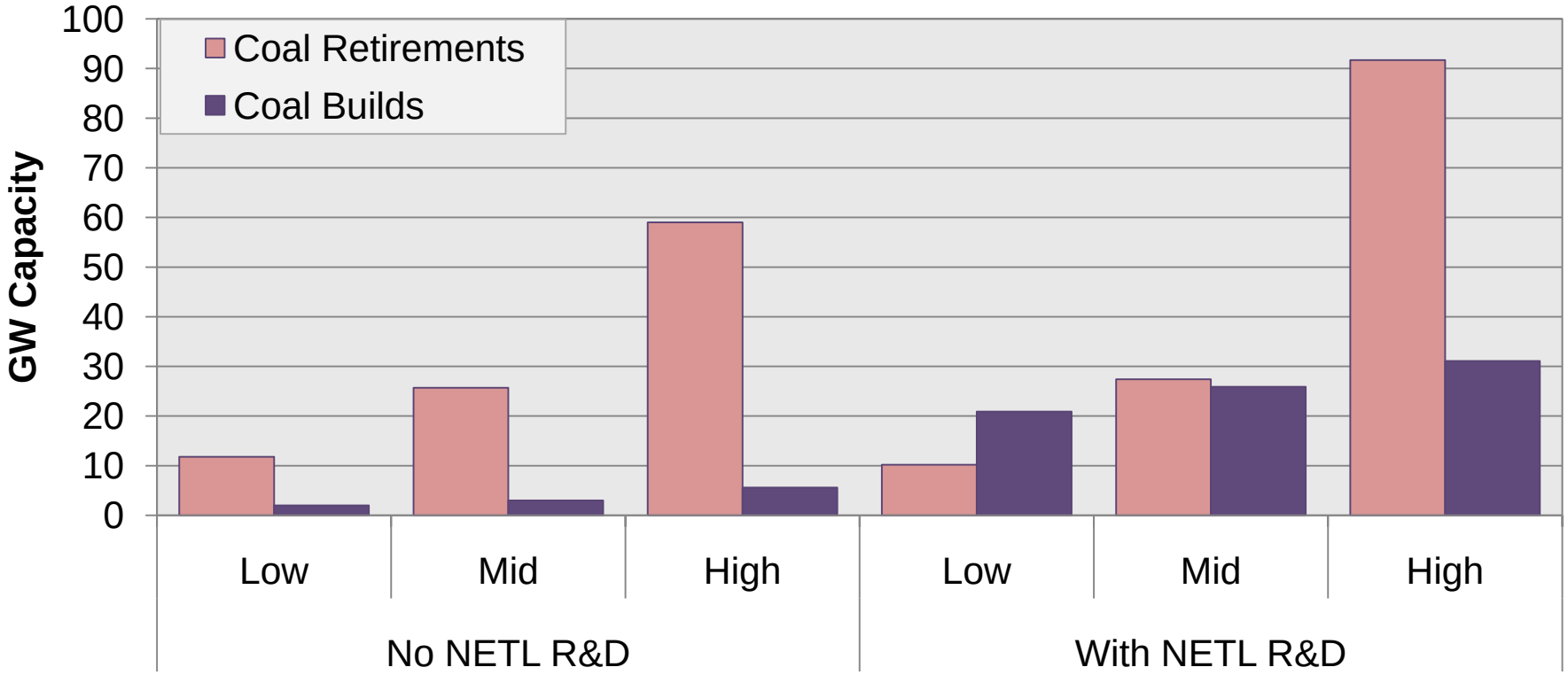
NEMS Run Results – IGCC and IGFC Builds by Year 2030



Effect of FE R&D on GHG Emissions

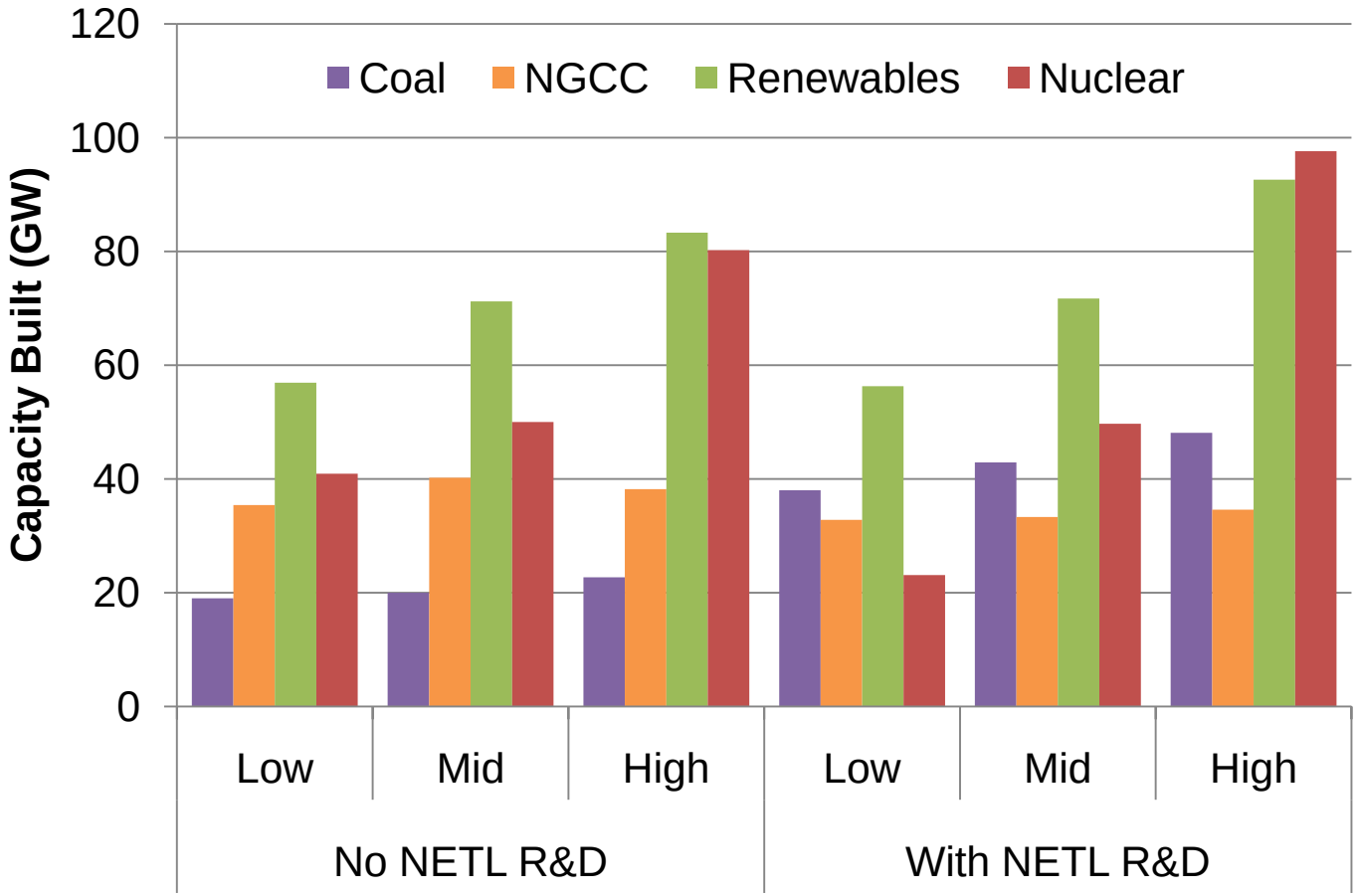
- **Under the mid CO2 tax scenario, FE R&D reduces GHG emissions by ~ 100 MMmtCO2/eyr in 2030**
- **Under the low CO2 tax scenario, FE R&D reduces GHG emissions by ~ 20 MMmtCO2e/yr in 2030**
- **It is difficult to draw conclusions from the high tax scenario results because of a curious increase in PC retirements in the with R&D case (likely a conversion anomaly)**
- **The price of electricity is largely unchanged across all cases. 30 GW is not enough to affect the marginal dispatch.**

NEMS Run Results – Coal Builds and Retirements by Year 2030



- **The high tax case retirements are different under the with and without FE R&D scenarios, complicating comparisons.**
- **The high tax scenario presents an opportunity, but new coal power is not selected for much of the replacement**

Increased Nuclear & Renewable Builds in NETL R&D Case Due to Increase in Retirements



3. NEMS Results with (1) Inputs Changed to Represent FE R&D for Advanced Coal Power and (2) NEMS Code Modified to Allow Retrofit of Existing Coal Power Plants for CO2 Capture

Input Changes – PC Refurbishment & Retrofit for CCS

- **Assumptions for IGCC and IGFC unchanged from previous**
- **Add code to allow existing CFPPs to refurbish and retrofit when economical***
  - No NETL R&D
    - Refurb: 3pp efficiency improvement, $160/kw to refurbish
    - Retrofit: Based on Conesville cost and performance
  - With NETL R&D
    - Refurb: same as the no NETL R&D case
    - Retrofit: Based on IEP Program Goals (next slide)

*Geisbrecht, Rodney, Extending the CCS Retrofit Market by Refurbishing Coal Fired Power Plants

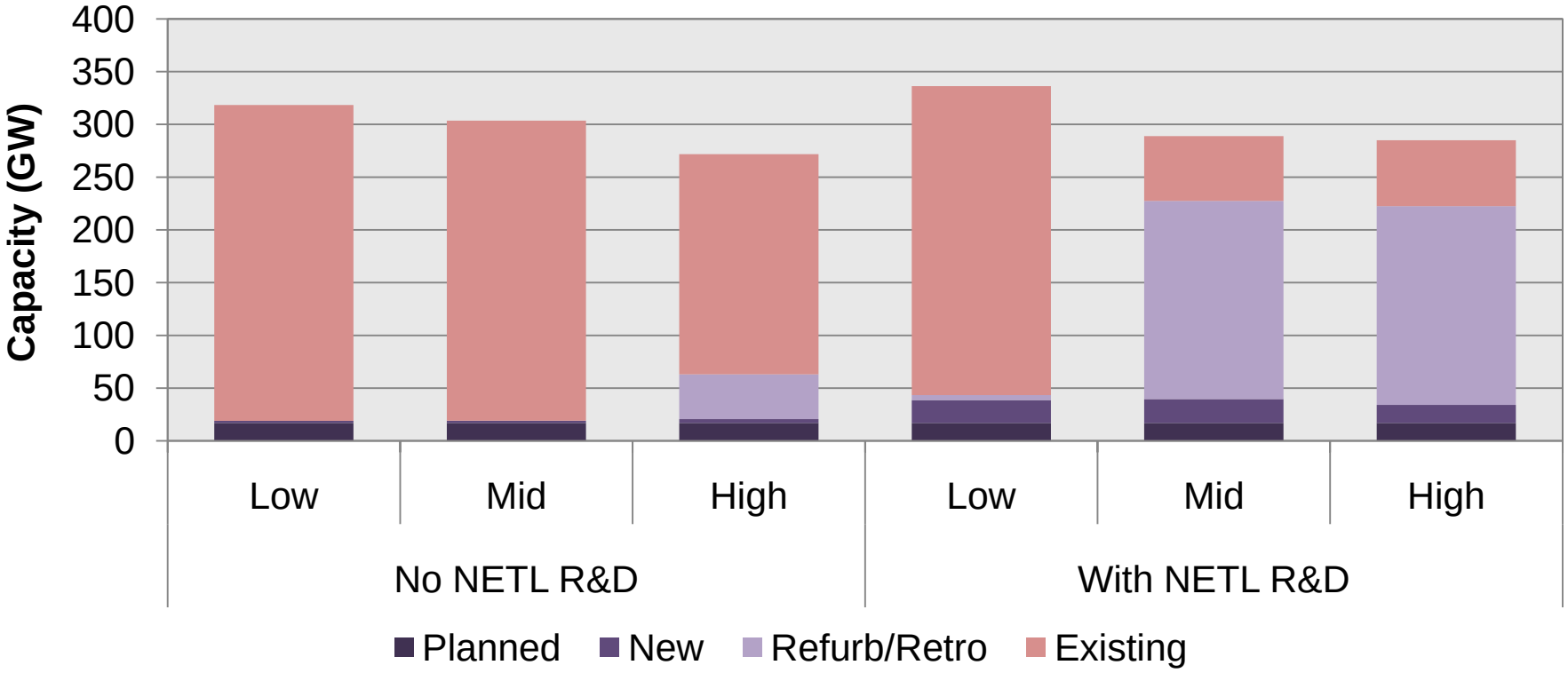
NEMS Input Summary – PC Refurbishment and Retrofit for CCS

		No NETL R&D	With NETL R&D
Refurbish &Retrofit	Online Year	2015	2015
	Starting Year Deployment Cap (GW)	5	5
	Deployment Cap Growth Rate % increase/yr	50%	50%
	Maximum Deployment Limit (GW)	226	226
	Capacity Loss	30.3%	16.5%
	LCOE Adjustment Factors* (mills/kwh)		
	Capital	23.92	16.95
	Fixed O&M	0.80	0.69
	Variable O&M	9.97	3.99
	Total Increase to LCOE (above existing plant)	34.69	21.63

**Assumes generating unit heat rate of 10800 btu/kwh. Cost adjustment factors calculated based on individual unit heat rate. Units with higher or lower heat rates will have different cost adjustment factors.*

Cost reduction potential under FE R&D program targets defined in: "CO2 Capture and Storage Cost Target for Existing Plants." Presented at the Coal Utilization Research Council. October 1, 2008.

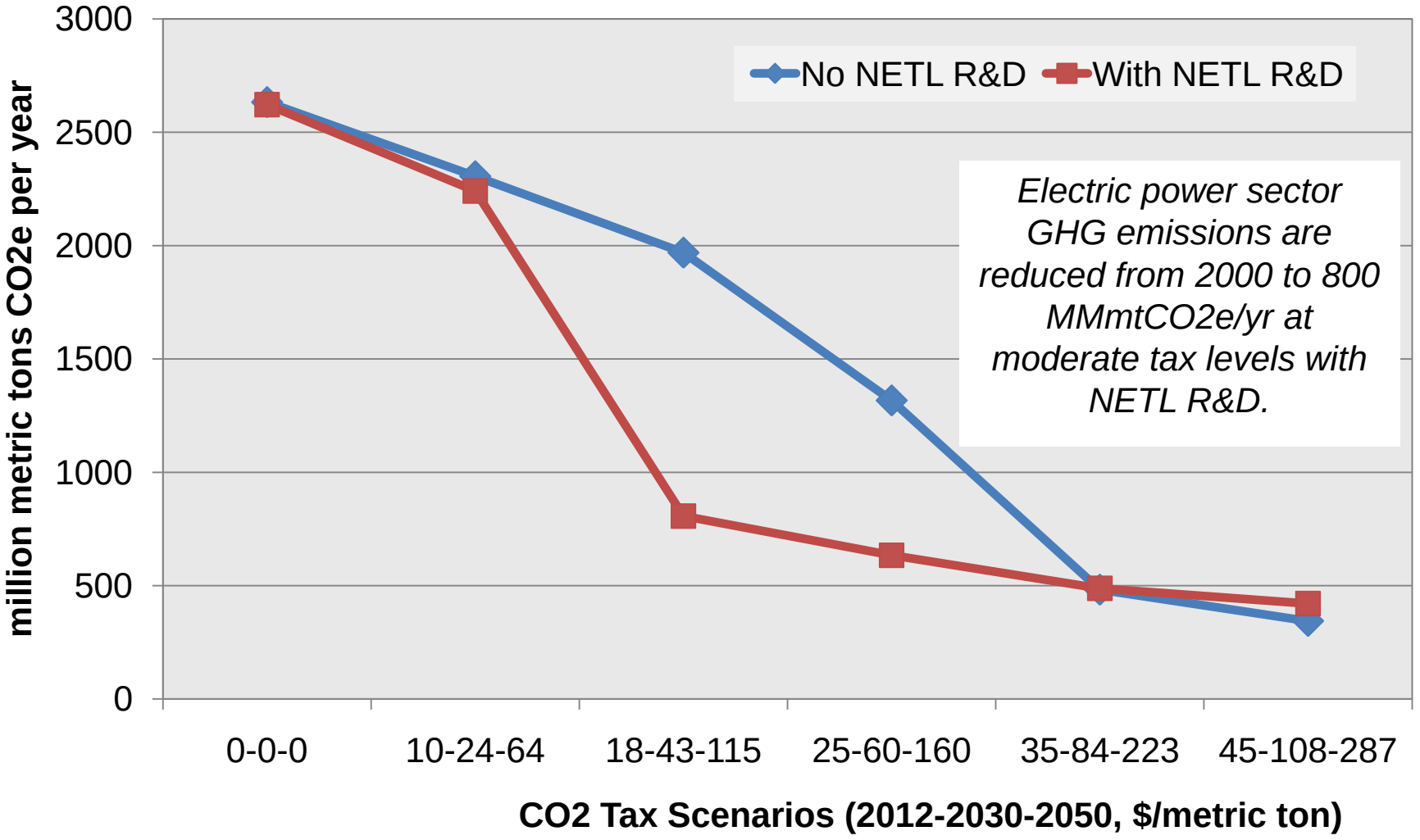
NEMS Run Results – Coal Builds & Retrofits by Year 2030



With NETL R&D most of the coal fleet is transformed in the mid CO_2 tax case.

Electric Power Sector CO2 Emissions in 2030

NEMS with FE R&D and code to allow PC retrofit



FE R&D Does Not Affect the Price of Electricity in NEMS

- **Most of the technology deployments are retrofitted PC plants which have a higher marginal cost than new plants.**
- **There is a significant capital cost benefit associated with retrofitting rather than building new (less capital outlay required), but it is not well recognized in the NEMS macroeconomic model**
- **Interpretation: electric bills remain unchanged, response to carbon tax greatly accelerated.**

Back-up Slides

Generation by Fuel Type in 2030

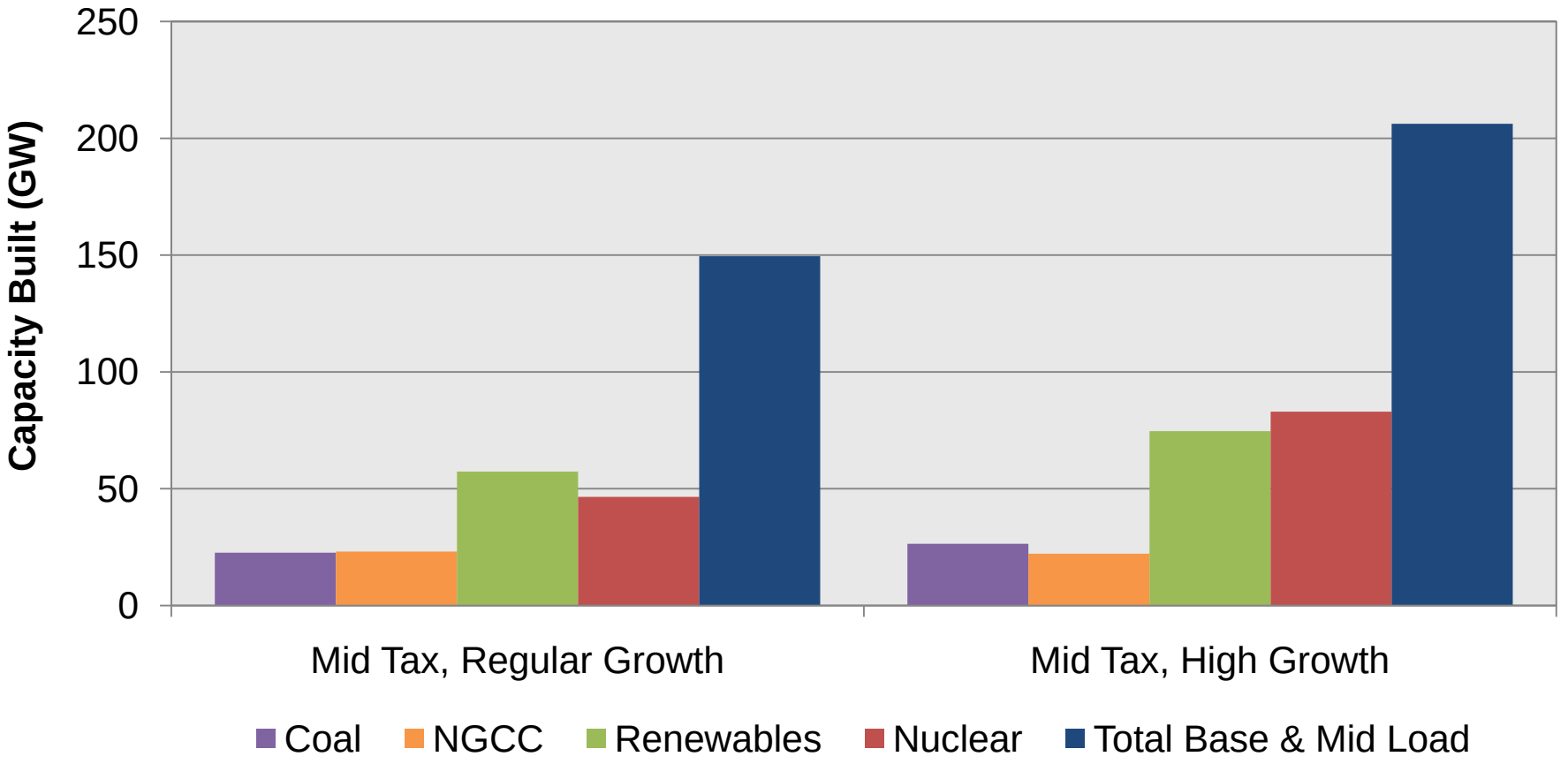
	PC Retrofits Not Allowed		PC Retrofits Allowed	
	No NETL R&D	With NETL R&D	No NETL R&D	With NETL R&D
Coal	36%	37%	36%	39%
Natural Gas	25%	25%	25%	25%
Nuclear	16%	15%	16%	16%
Renewables/ other	23%	23%	23%	20%

High Macro Assumption Increases Power Consumption in 2030 by 9% (400 BkWh)

	GDP (Billion 2000 Chain Weighted $)	Electric Intensity (kWh/$ 2000 GDP)	Electric Consumption (BkWh)
18 CO2 Tax, Regular Growth	19840	0.23	4510
18 CO2 Tax, High Growth	22567	0.22	4906

Higher electric demand due to faster GDP growth.

High Macro Baseload Builds by 2030 Mid CO_2 Case



High Macro causes an increase in new power plant builds of 58GW through 2030, coal power deployments increase by only 4 GW.